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Residual Effect of Phosphorus Fertilizer on Yield of Pigeon Pea (*Cajanas cajan*) in Ultisol

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Phosphorus (P) is one of the essential plant nutrients and plays an important role in nitrogen fixation of leguminous crops. A two-year experiment was conducted at the Teaching and Research Farm of Ambrose Alli University, Ekpoma, Nigeria to investigate the effect of different rates of phosphorus fertilizer on the growth, yield, nodulation and nutrient uptake of pigeon pea (*Cajanas cajan*). Seven P rates (0kg (control), 25, 50, 75, 100, 125 and 150kg ha^{-1}) were laid out in a Randomized Complete Block Design with three replicates and managed for two consecutive years. Data on plant growth, yield, nutrient uptake and soil properties were collected for the two seasons. The application of phosphorus significantly increased the soil nutrient content after the first season. There was no significant difference in height and stem girth of pigeon pea. The application of 75 kg ha^{-1} significantly (p=.05) increased the number of leaves, biomass and nodules of pigeon pea. The application of 25 - 75kg ha^{-1} of phosphorus fertilizer increased the grain yield of pigeon pea than other rates of application in the first cropping season. In the residual experiment, the control and 25kg ha^{-1} application of P had the grain yield of 1,493.3kg ha^{-1} and 1,498.0kg ha^{-1} respectively, and were significantly (p=.05) higher compared to other treatments. The application of phosphorus fertilizer at the rate of 25 – 75kg ha^{-1} significantly improved the yield, nodulation and nutrient uptake of pigeon pea in degraded ultisol. Increasing the quantity of P fertilizer above 25kg ha^{-1} showed no significant difference in the yield of pigeon pea, it will be more ideal to use 25kg ha^{-1} as the recommended rate.

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1. INTRODUCTION

Pigeon pea (*Cajanus cajan*) is a leguminous food grain shrub rich in protein and contain good quality carbohydrate, crude fibre and lipids. It is also a source of dietary minerals and vitamins (Thiamine, Riboflavin and Niacin). The intercrop of pigeon pea as a cover crop with maize, increases maize yield [1]. In addition to its food uses, pigeon pea has outstanding soil amelioration and conservation properties. The growth habit facilitates soil protection as it form canopy which help to control erosion.

Pigeon pea produces more nitrogen from plant biomass per unit area of land than many other legumes and it also fixes atmospheric nitrogen. Benefits of pigeon pea as leguminous cover crop includes; improve soil fertility, weed competition and increased arthropod diversity [2]. Pigeon pea when used as green manure provides the benefit of improving long term soil quality and fertility. Pigeon pea is drought resistant due to its deep rooting system and osmotic adjustment in the leaves; it also helps to mitigate the impacts of climate change [3,4].

The yields of pigeon pea in tropics are generally low due to nutrient deficiency, it is therefore necessary to apply fertilizer to boost its growth and yield. The application of macro and micronutrients in optimum quantity and right proportion is essential in crop production. The application of organic and inorganic fertilizer contributes significantly to the growth and yield of *C. cajan*. Phosphorus is an essential macronutrient in plants as it is part of Adenosine Triphosphate (ATP), DNA, RNA and plays a major role in energy storage and transfer. Due to its importance in biological activities in plants, phosphorus plays an important role in the growth and yield of pigeon pea [5].

The application of small quantity of P at the rate of 36kg ha^{-1} significantly increased the growth, yield and nodulation of pigeon pea [2]. It has been reported that the application of 26.4kg P ha^{-1} significantly improved seed yield, nodulation and nitrogenase activity in pea [6]. Also, it was reported that the application of 17- 43kg P ha^{-1} significantly improved the growth and yield of *C. cajan* in nutrient depleted soil [7,8].

The response of pigeon pea to P fertilization would not be expected in soil with more than 5 mg/kg of extractable P, hence, the pre-existing P concentration was adequate for the growth of pigeon pea before the application of P four weeks after planting [9]. Phosphorus deficiency is a problem in highly weathered ultisols and this condition adversely affects crop production.

Ekpoma soils are classified as ultisol and are generally low in available phosphorus and it was necessary to apply some quantity of phosphorus fertilizer to improve the yield and nodulation of pigeon pea. This research has not been carried out in this area and it was therefore important to investigate the rate of phosphorus fertilizer application that will best suit pigeon pea production in this area.

2. MATERIALS AND METHODS

2.1 Description of Experimental Site

Ekpoma lies between Latitude 6º45' 34" North and longitude 6º8' 27" East with average annual rainfall of about 1500mm. Two years field experiment was carried out at the Teaching and Research Farm, Ambrose Alli University, Ekpoma, Nigeria in 2010 and the residual experiment was conducted in 2011.

2.2 Experimental Design

The experimental design was a randomized complete block design with seven treatments and three replicates. The treatments include: 0 (control), 25, 50, 75, 100, 125 and 150kg ha^{-1} of Phosphorus fertilizer. P was applied in form of single super phosphate containing 18 % of P. The fertilizer rates was applied at four weeks after planting. The plot measured 4.0m x 3.0 m and the field was manually tilled with hoe. A long duration varieties of pigeon pea used was IAR&T50. The planting distance was 1mx1m, the seed were sown at the rate of 3 - 4 seeds per stand and later thinned to one plant per stand at three weeks of planting. The field was weeded twice manually and no irrigation water was applied because it was rain fed. The height, stem girth and number of leaves were measured at 2, 6, 10 weeks after fertilizer application. The application of P fertilizer was carried out during the first season only; the second season was to investigate its residual effect on pigeon pea. The shoot was oven dried to a constant weight to determine the dry matter weight. Nodules count, weight and index were evaluated for the first cropping season only. The grain yield of pigeon pea for the first and second season was recorded.

2.3 Soil Analysis

The pre planting soil analysis was carried out and soil from each replicates of the same treatment were bucked for analysis in 2011. Top soils (0-15 cm) were collected from the site prior to each planting season, the soils were air dried, sieved and the samples were analysed for both chemical and physical properties.

Particle size analysis was carried out using hydrometer method [10]. The pH was determined in water (ratio1:1, soil: water). Soil pH in KCl (1:1), 20g of soil and 20ml of water was used and equilibrated for 30 minutes with occasional stirring. pH was determined and measured in KCl [11]. Organic carbon was determined by wet dichromate method [12] and Available phosphorus by Bray extraction method [13]. Total nitrogen was determined by Kjeldahl method [14]

Exchangeable cations (potassium, calcium and magnesium) were extracted with ammonium acetate. Potassium was determined by flame photometer while calcium and magnesium by atomic absorption spectrophotometer [11]. Micronutrients such as copper, zinc, iron and manganese were also determined using the method described [15].

2.4 Data Analysis

The nutrient uptake; nitrogen, phosphorus and potassium in pigeon pea were also calculated by multiplying nutrient concentration in the plant tissue by the dry matter weight, that is:

Nutrient uptake = concentration x dry matter yield.
Nodules index = (Dry weight of nodules / Dry weight of shoot) x 100 [16].

Data collected were analysed using Anova and Duncan's multiple range test was used to separate means.

3. RESULTS AND DISCUSSION

3.1 Soil Analysis

The soil pH was not significantly (p=.05) different among treatments however there was increase in pH in 2011 compared to the initial pH in 2010. The pre planting soil analysis was deficient in organic matter and other essential nutrients mostly nitrogen, phosphorus, potassium, magnesium. The soil was slightly acidic with sandy loam texture (Table 3). It was observed that, there was significant (p=.05) increase in the soil nutrient content in 2011 compared to the pre planting soil analysis in 2010 (Table 3). There was significant (p=.05) increase in organic carbon, nitrogen, phosphorus, potassium, calcium, magnesium and sodium in the soil for the residual experiment in 2011 compared to the pre planting soil analysis in 2010. Also the application of 125kg ha^{-1} application of P to pigeon pea increased the ECEC of the soil than other application rate. The iron content in the soil ranges from 39.42mg g^{-1} in 150 kg ha^{-1} to 77.63mg g^{-1} at the application of 25kg ha^{-1} of P. Application of 25kg ha^{-1} of P significantly (p=.05) increase iron content of the soil compared to other application rate. Copper and zinc were higher in 50kg ha^{-1} and 150kg ha^{-1} of phosphorus application (Table 3).

3.2 Growth Parameters of Pigeon Pea

There was no significant difference in the height of pigeon pea with or without the application of P. P application rate of 75kg ha^{-1} significantly (p=.05) increased the stem girth of *C. cajan* at ten weeks after planting compared to other rates of application (Table 1). It was also observed that the application of 75kg ha^{-1} of phosphorus significantly (p=.05) increased the number of leaves of pigeon pea compared to other treatments throughout the growth season (Table1). In the residual experiment, there is no significant difference in pigeon pea's height and stem girth. The number of leaves of pigeon pea was increased at twelve and sixteen weeks after planting with the application of 25kg ha^{-1} of fertilizer compared to other treatments (Table 4).

3.3 Nodulation and Yield of Pigeon Pea

The application of 75kg ha^{-1} of phosphorus fertilizer increased nodules count and weight by 52.9 % and 54.7 % respectively than the control and the values were significantly (p=.05) higher compared to other rate of application (Table 2). Also the nodules index and above ground biomass of *C. cajan* were significantly (p=.05) higher in 75kg ha^{-1} fertilizer application compared to other treatments. The application of 25–75kg ha^{-1} of phosphorus fertilizer significantly (p=.05) increased the grain yield of pigeon pea compared to other treatments. The application of 25kg ha^{-1} of fertilizer had the highest pigeon pea grain yield and it was 53.8% higher than the control (Table 2).

Table 1. Effect of different levels of phosphorus fertilizer on pigeon pea's height, stem girth and number of leaves

	Weeks after phosphorus fertilizer application								
	← Height (cm) →			← Stem girth (cm^2) →			← Number of leaves →		
Treatments	**2**	**6**	**10**	**2**	**6**	**10**	**2**	**6**	**10**
0	47.100a	84.47a	144.20a	3.03a	3.87a	4.30b	76.33b	262.7c	1265.3b
25	42.667a	86.87a	148.14a	2.97a	3.80a	4.48b	69.00b	295.7c	987.7c
50	45.900a	98.67a	161.67a	2.97a	4.00a	4.82b	74.67b	355.0b	1438.0b
75	52.100a	97.80a	161.33a	3.13a	4.50a	5.86a	112.33a	562.0a	1883.3a
100	45.900a	80.13a	135.97a	2.83a	3.70a	4.98b	70.00b	274.3c	892.3c
125	44.900a	92.47a	156.43a	2.93a	3.93a	4.18b	81.67b	393.7b	1398.7b
150	46.233a	86.67a	151.57a	2.83a	3.87a	4.65b	73.00b	375.7b	1137.7b
	NS	NS	NS	NS	NS				
SE	6.81	9.47	12.30	1.71	1.98	2.18	8.92	18.96	31.89

Mean values followed by the same letter under the same vertical column are not significantly ($p \leq 0.05$) different according to Duncan's multiple range test

Table 2. Effect of different levels of phosphorus fertilizer on nodules count, dry weight, index, dry matter weight of shoots, leaves and grain yield pigeon pea

Treatments	Number of Nodules ha^{-1}	Weight of Nodules (kg ha^{-1})	Nodules Index	Dry matter wt. of shoots (kg ha^{-1})	Dry matter wt. of leaves (kg ha^{-1})	Grain Yield (kg ha^{-1})
0	576.70c	8.00c	0.24c	3,101.00a	1,003.00b	495.00c
25	666.70c	9.000c	0.27c	3,333.00a	1,333.00b	1,071.00a
50	620.00c	8.00c	0.22c	3,667.00a	1,500.00b	969.70a
75	1223.30b	17.67a	0.44a	3,833.00a	2,000.00a	990.30a
100	673.30c	11.00b	0.35b	3,167.00b	1,500.00b	711.70b
125	1206.70a	13.33b	0.38b	3,500.00a	1,500.00b	884.30b
150	876.70c	10.33b	0.28c	3,667.00a	1,833.00a	857.30b
SE	23.96	3.32	0.56	58.88	39.04	29.23

Mean values followed by the same letter on the same vertical column are not significantly ($p \leq 0.05$) different according to Duncan's multiple range test

Table 3. Physico-chemical properties of soil used for the pre planting and residual experiment

Parameters	Application of phosphorus fertilizer per hectare (kg ha^{-1})								
	O kg ha^{-1}	**25 kg ha^{-1}**	**50kgha^{-1}**	**75kgha^{-1}**	**100kgha^{-1}**	**125kgha^{-1}**	**150kgha^{-1}**	**Pre planting**	**SE**	**Methods**
pH (1:1) H_2O	5.64a	5.60a	5.65a	5.85a	5.73a	5.92a	5.71a	5.40a	0.84	Glass electrode pH meter [11]
OC (g kg^{-1})	21.50a	19.70a	19.00a	20.50a	18.00a	15.40b	20.30a	14.90b	1.54	Wet dichromate [12]
N (g kg^{-1})	2.20a	2.00a	1.70a	2.10a	1.70a	1.60a	2.10a	0.36b	0.43	Modified Kjeldal [14]
P (mg g^{-1})	12.52a	12.32a	11.29a	10.86a	10.00a	11.83a	11.47a	8.04b	1.17	Bray 1 [13]
Ca (cmol kg^{-1})	0.80b	0.89b	1.30a	1.08a	1.20a	1.01a	1.27a	0.57c	0.35	Atomic Absorption Spectrophotometer [11]
Mg (cmol kg^{-1})	1.07a	1.11a	1.30a	1.08a	1.20a	1.10a	1.27a	0.36b	0.36	
K (cmol kg^{-1})	0.19a	0.22a	0.22a	0.13b	0.15b	0.18a	0.24a	0.08c	0.14	Flame photometer [11]
Na (cmol kg^{-1})	0.43a	0.43a	0.76a	0.38a	0.41a	0.41a	0.71a	0.10b	0.23	
H^+ (cmol kg^{-1})	1.20b	0.56c	0.56c	0.64c	0.80c	2.56a	0.80c	0.60c	0.34	
Al^{3+} (cmol kg^{-1})	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	ns	
ECEC	3.69b	3.21b	4.14b	3.16b	3.71b	5.26a	4.20b	1.71c	0.67	
Mn (mg kg^{-1})	57.81b	63.54b	61.93b	72.57a	78.19a	72.91a	71.93a	69.34b	2.93	DTPA soil test [15]
Fe (mg kg^{-1})	61.60b	77.63a	55.62b	40.44c	42.83c	43.14c	39.42c	41.82c	2.50	
Cu (mg kg^{-1})	0.70c	0.66c	1.07b	0.53c	0.68c	0.69c	0.60c	7.83a	0.4513.60a	
Zn (mg kg^{-1})	6.83b	5.29b	5.72b	5.54b	7.83b	6.64b	2.63c	0.91		
Particle size analysis										
Sand (g kg^{-1})	842	832	852	852	852	852	852	876		Hydrometer method [10]
Silt (g kg^{-1})	34	34	34	34	34	34	34	20		
Clay (g kg^{-1})	124	134	114	114	114	114	114	104		
Textural Class	Sandy Loam									

Table 4. Residual effect of different rates of phosphorus fertilizer on pigeon pea's height, stem girth and number of leaves

	Weeks after phosphorus fertilizer application											
	← Height (cm) →				← Stem girth (mm^2) →				← Number of leaves →			
Treatments	**8**	**12**	**16**	**20**	**8**	**12**	**16**	**20**	**8**	**12**	**16**	**20**
0	83.57	172.47	245.33	386.67	3.08	8.97	25.18	30.92	71.67	349.00	1,202.30a	1,534.00a
25	93.60	171.50	269.83	370.00	4.84	9.67	22.15	27.15	91.67	390.30	1,200.70a	1,495.30a
50	90.83	189.43	295.00	382.69	3.40	10.25	22.15	27.25	94.67	256.30	834.30b	1,145.30b
75	88.27	183.33	280.07	391.50	4.22	10.56	26.33	31.84	84.00	360.30	1,362.70a	1,592.70a
100	86.23	164.00	231.03	318.00	4.80	9.25	19.00	24.39	90.33	167.00	879.40b	1,212.00b
125	80.90	156.17	230.00	314.00	2.87	7.85	17.18	25.11	76.67	206.70	709.00b	1,198.70b
150	68.69	136.43	209.50	306.67	2.27	7.20	16.31	22.12	69.33	177.00	432.00c	1,144.00b
	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS		
SE	8.61	12.94	16.23	17.52	1.90	3.01	4.60	5.19	9.09	16.50	49.90	36.49

Mean values followed by the same letter under the same vertical column are not significantly different according to Duncan's multiple range test ($p \leq 0.05$)

Table 5. Residual effect of different rates of phosphorus fertilizer on nutrient uptake, dry matter and grain yield of pigeon pea (tonnes ha^{-1})

	Application rate of phosphorus fertilizer							
Treatments	**0**	**25**	**50**	**75**	**100**	**125**	**150**	**SE**
N	113.00a	95.77a	113.60a	117.8a	94.67a	39.7b	19.50b	8.31
P	8.37b	4.90b	10.93a	6.50c	5.23d	4.40d	3.17e	2.49
K	40.47a	32.5b	26.87c	25.50bc	21.83d	29.40b	24.27d	5.35
Dry matter yield	3.11a	3.13a	3.20a	3.11a	2.66b	3.03a	2.13b	1.72
Grain yield	1.49a	1.50a	1.23a	1.10a	0.78b	0.55b	0.33b	1.00

Mean values followed by the same letter on the same row are not significantly different according to Duncan's multiple range test ($p \leq 0.05$)

3.4 Nutrient Uptake (Tonnes Ha^{-1})

The nitrogen uptake of *C. cajan* was significantly lower (p=.05) at the rate of 125 kg ha^{-1} and 150 kg ha^{-1} application of P fertilizer (Table 5). Phosphorus uptake in *C. cajan* at 50kg ha^{-1} was 10.9 tonnes per hectare and this was significantly (p=.05) higher compared to other treatments. The control (0 kg ha^{-1}) had the highest uptake of potassium of 40.5 tonnes per hectare and the value was higher than other treatments (Table 5).

3.5 Dry Matter and Grain Yield (Tonnnes ha^{-1})

The dry matter weight of pigeon pea was higher at the application of 50 kg ha^{-1} of phosphorus fertilizer with the value of 3.2 tonnes ha^{-1} while the least dry matter weight was recorded in 150 kg ha^{-1} of fertilizer with the value 2.13 tonnes ha^{-1} (Table 5).The grain yields of pigeon pea were significantly (p=.05) higher at the application rate of 25 - 75kg ha^{-1} of fertilizer compared to other rate of application but the values were not different from the control (Table 5 above).

3.6 Discussion

The cultivation of pigeon pea increased the soil organic matter due to its litter fall which decomposed into organic matter and this confirmed the earlier work done [17]. Also the cultivation of pigeon pea and the addition of small quantity of phosphorus fertilizer increased the essential nutrient elements (nitrogen, phosphorus, potassium, magnesium) above the critical values [18]. Legume such as pigeon pea improve soil fertility and these include maintenance and improvement of soil physical properties, providing ground cover to reduce soil erosion, increasing soil organic matter, cation exchange capacity, microbial activity and reduction of soil temperature [19]. There was higher phosphorus content in the soil after the first season, which indicated that pigeon pea can utilized and mined phosphorus due of its deep rooting system and this has earlier been reported [20,21].

The growth of pigeon pea was significantly influenced by the application of small quantity of phosphorus fertilizer but heavy application of phosphorus above 75kg ha^{-1}does not improved the growth and yield of pigeon pea. Oversupply of P caused decrease in plant growth, nodulation and acetylene reduction in legumes [22]. The nutrient (nitrogen, phosphorus and potassium) uptake in pigeon pea was significantly (p=0.05) higher above the critical value due to the application of small quantity of phosphorus fertilizer. There was significant interaction between phosphorus fertilizer and pigeon pea which enhanced nutrient uptake [23,24]. The control (0 kg ha^{-1}) significantly increased the residual uptake of potassium and this has earlier been reported [25].

The application of 50 kg ha^{-1} of P fertilizer significantly (p=.05) increased the phosphorus uptake of *C. cajan*. This showed that pigeon pea requires small amount of fertilizer to enhance its P uptake [26]. The application of P at the rate of 25 kg ha^{-1} – 75kg ha^{-1} significantly (p=.05) improved the growth, yield, nodulation and nutrient uptake of pigeon pea. It has been reported that legumes such as pigeon pea response to small quantity of P depending upon P status of soil [2,27]. The residual effect of P did not significantly influence the growth and yield of pigeon pea. It is therefore evidence that P has little or no residual effects on the growth and yield of pigeon pea.

4. CONCLUSION

The application rate of 25 – 75kg ha^{-1} of P fertilizer significantly improved the growth and yield of *C. cajan*. It was also observed the application of 25 – 75kg ha^{-1} rate of phosphorus fertilizer increased the nodulation and nutrient uptake of pigeon pea. The application of 25 – 75 kg ha^{-1} of P fertilizer significantly improve the nutrient status of the soil. From the experiment, P fertilizer had little or no residual effect on growth and yield of *C. cajan.* Application of P fertilizer above 75 kg ha^{-1} reduced the yield of pigeon pea. P fertilizer above 25 kg ha^{-1} did not further increase the grain yield of pigeon pea, therefore depending on the purpose of pigeon pea cultivation, the application of 25 kg ha^{-1} of phosphorus fertilizer is recommended for grain yield, 75 kg ha^{-1} for cover crop and erosion control and 50 kg ha^{-1} for fodder

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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